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DYNAMIC METHOD FOR MEASURING THE NON-LINEARITITES OF PHOTOELECTRIC DETECTORS

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16. Abstract

The photocurrent of a nonlinear radiation detector contains a signal with the frequency $\omega_1 - \omega_2$ when exposed to two chopped light beams with the chopper frequencies ω_1 and ω_2. The amplitude of the intermodulation signal is proportional to the non-linearity. So it is possible to measure nonlinearities in a direct way without evaluating small differences of large quantities. The method shown requires less stability of light sources than classical methods. A dependence of the intermodulation signal on the chopper frequencies gives additional information about time dependent nonlinearities.

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Dynamic Method for Measuring the Nonlinearities of Photoelectric Detectors

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The photocurrent of a nonlinear radiation detector contains a signal with the frequency $\omega_1 - \omega_2$ when exposed to two chopped light beams with the chopper frequencies ω_1 and ω_2. The amplitude of the intermodulation signal is proportional to the nonlinearity. So it is possible to measure nonlinearities in a direct way without evaluating small differences of large quantities. The method shown requires less stability of light sources than classical methods. A dependence of the intermodulation signal on the chopper frequencies gives additional information about time dependent nonlinearities.

Introduction

Spectral sensitivity is an important factor in the determination of the usefulness of a radiation detector for precision measurements in photometry and spectroscopy. Other important criteria are time stability and deviations from the linear context between the photoelectric current and the impinging radiation. The most accurate method for checking linearity known to date is the constant light addition method. It has been used in different variations for photoelectron multipliers and photoelectric cells by Bischoff [1], Kunz [2], Cohen, Hübner, and Sutter [3], Sanders [4], and other authors. Kunz's measurements especially indicate that photoelectron multipliers might be extremely well suited for precision measurements of radial intensities per unit area. This study describes a method for measuring nonlinearities which is based on the principle of frequency modulation. This method allows the measurement of very small nonlinearities and provides, in conjunction with the constant light method, additional information on the time dependency of the nonlinearity.

Measuring Principles; Comparison to the Conventional Constant Light Method

The behavior of a radiation detector with a short reaction time can frequently be described with good approximation by the characterization

$$i = BP + CP^2 + DP^3 \quad |CP^2|, |DP^3| \ll |BP| \tag{1}$$

B, C, D: constants

i is the photoelectric current or original current, while P is the impinging radiation capacity which may be a function of time. The conventional constant light method to measure nonlinearities consists in exposing the detector to the radiation capacities P_1, $P_1 + P_2$, and P_2. The photoelectric currents observed during this process, i_1, i_{1+2}, and i_2 then constitute a measure on the nonlinearity NL which shall be defined as follows:

$$NL_G(i_{1+2}) = 2\,\frac{i_{1+2} - (i_1 + i_2)}{i_{1+2}}. \tag{2}$$

Figure 1 illustrates the significance of this definition. By inserting equation (1) into equation (2), we arrive at the expression

$$NL_G(i_{1+2}) = \frac{1}{B}\,(CP + \frac{3}{2}DP^2). \tag{3}$$

for nonlinearity as a function of the total photoelectric current. Here, radiation capacities $P_1 = P_2 = 0.5$ P were chosen, and small quantities with the coefficients C and D in the denominator of eq. (2) were disregarded.

In the dynamic method being described here, two chopped light beams with the chopper frequencies ω_1 and ω_2 ($\omega_1 > \omega_2$) impinge on the detector (cf. Fig. 2) at the same time. The photoelectric current of a strictly linear detector ($C = D = 0$) will then only contain the frequencies

$$n\,\omega_1 \text{ und } k\,\omega_2, \qquad n, k = 1, 2, 3, \ldots{}^{1},$$

whose amplitudes are fixed by the shape and height of the light pulses. As soon as at least one of the coefficients C and D differs from zero, the frequency spectrum

$$n\,\omega_1 \pm k\,\omega_2, \qquad n, k = 1, 2, 3, \ldots \quad n \geqq k, \tag{4}$$

appears in the photoelectric current, i.e. additional combination of modulated frequencies are being generated whose amplitudes are functions of the light pulse shape and height and of coefficients C and D. The smallest combination frequency $\omega_1 - \omega_2$ can be most easily separated from the basic frequencies ω_1 and ω_2 by filters, its amplitude is used as the measure of the nonlinearity of the detector. In our case, both light beams were chopped into rectangular shapes by an oscillating metal tongue which was mounted in front of a slot (cf. Fig. 2).

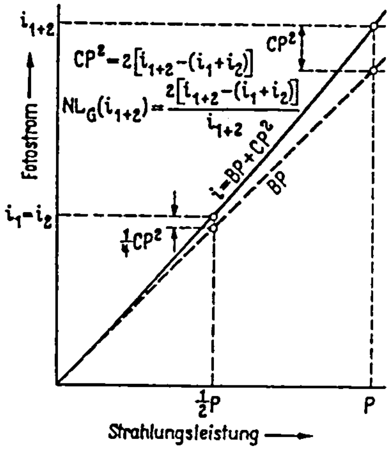

Figure 1
On the definition of the measure of nonlinearity NL_G

[1] In a purely sinusoidal modulation, $n = k = 1$, however, this is not necessary for the proper functioning of the dynamic method.

The Fourier series for the entire light beam, modulated in such a fashion, reads:

$$\left.\begin{aligned} P(t) &= \frac{P}{4}\left[2 + \sum_{n=1}^{\infty} a_n(\sin n\,\omega_1 t + \sin n\,\omega_2 t)\right], \\ a_n &= \frac{2}{\pi n}[1 - (-1)^n]. \end{aligned}\right\} \tag{5}$$

Here, P is the maximum radiation capacity which is received by the detector if both choppers are fully open. When radiation capacity P(t) according to eq. (5) is inserted into eq. (1) and the square and cubic terms are converted, the frequency spectrum according to (4) results. This is due to the identity

$$\sin\alpha \cdot \sin\beta = \frac{1}{2}[\cos(\alpha - \beta) - \cos(\alpha + \beta)]$$

For the portion of the photoelectric current of frequency $\omega_1 - \omega_2$, which is of primary interest here, amplitude

$$A(\omega_1 - \omega_2) = \frac{1}{\pi^2}\left(C P^2 + \frac{3}{2} D P^3\right). \tag{6a}$$

results. The portion of the direct wave with frequency ω_1 has an amplitude of

$$A(\omega_1) = \frac{B P}{\pi}. \tag{6b}$$

In eq. (6b), quantities with the factors of C and D were again disregarded. The ratio $A(\omega_1 - \omega_2)$ to $A(\omega_1)$ is a reasonable measure of nonlinearity. However, in order to maintain the equality between the dynamic NL measure NL_D and the NL measure NL_G which is determined by the constant light method, we define[2]

[2] In a sinusoidal modulation, factor π in the definition of eq. (7) must be replaced by a factor of 4 in order to achieve equality of NL_D and NL_G.

$$NL_D(\hat{i}) = \pi \cdot \frac{A(\omega_1-\omega_2)}{A(\omega_1)} = \frac{1}{B}\left(CP + \frac{3}{2}DP^2\right). \qquad (7)$$

in which $\hat{i}$, just like i_{1+2} in eq. (3), represents the maximum value of the photoelectric current during a measuring cycle, i.e. when both modulators are fully open at the same time.

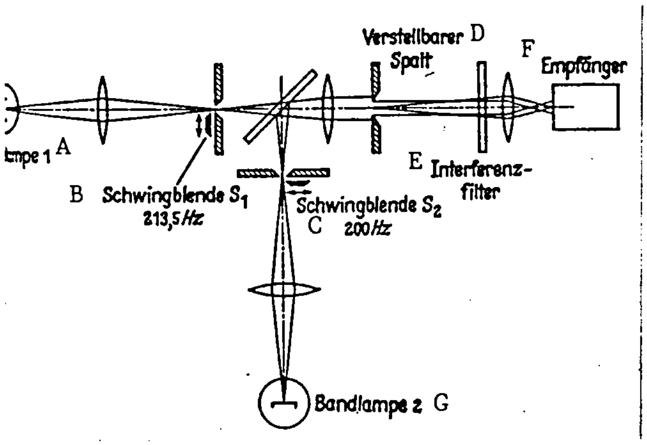

Figure 2
Optical Configuration of the measuring apparatus

A = ribbon lamp 1
B = chopper S1
C = chopper S2
D = adjustable slot
E = interference filter
F = detector
G = ribbon lamp 2

Time-Dependent Nonlinearities

Equation (1) is too simple an approach for many detectors. For instance, it happens frequently that a nonlinear portion of the photoelectric current builds up from the moment a constant radiation capacity P is turned on. Such behavior frequently can be approximated in the form

$$i = BP + CP^2\left(1 - e^{-\frac{t}{\tau}}\right) \tag{8}$$

with t being the time which elapsed from the moment the radiation capacity was turned on, and τ being a constant.

The information contained in equation (8) must first be generalized for an arbitrary, time-dependent P(t). This is done most easily with the two equations

$$\begin{gathered} i = B \cdot P(t) \cdot v(t)\,, \\ v(t) + \tau\frac{dv}{dt} = 1 + \frac{C}{B} \cdot P(t)\,. \end{gathered} \tag{9}$$

In this representation, v is a time-dependent amplification which is only slightly different from one, and whose course is determined by P(t) and τ. The resolution of the equation system (9) with the conditions

$$v(0) = 1,\ P(t) = \begin{cases} 0, & t < 0 \\ P, & t > 0 \end{cases}$$

results in the special case of eq. (8), and for $\tau = 0$, we immediately arrive at eq. (1) with D = 0. That means that equation system (9) is identical to equation (1) if D = 0 and $\tau = 0$. Because the "step function" F(t) occurs, it is useful to solve the differential equation with the Laplace transformation[3] .

It is to be expected that the NL signal obtained by the dynamic method decreases as time constant τ increases, so that the time constant can be determined by comparing the two values NL_G and NL_D. When we insert the Fourier series eq. (5) for the entire pulsed light signal into equation system (9), we arrive at

$$NL_D(\hat{t}, \omega\tau) = \frac{CP}{B} \cdot \frac{1}{1+(\omega\tau)^2}, \tag{10}$$

i.e.

$$NL_D = \frac{1}{1+(\omega\tau)^2} \cdot NL_G .$$

This applies with good approximation for closely adjacent chopper frequencies

$$\omega_1 - \omega_2 \ll \omega_1, \omega_2, \quad \omega_1 \approx \omega_2, \quad \omega = \frac{1}{2}(\omega_1 + \omega_2).$$

It is possible to measure time constants in the range of milliseconds for an NL of the magnitude 10^{-3}. It is important to know the time constants when deciding if and to what extent the linearity of a photoelectric detector can be improved in a photometric comparison by inserting a rotating sector (to keep the mean load of photoelectric current constant).

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[3] Cf. G. Doetsch, Tabellen zur Laplace-Transformation und Anleitung zum Gebrauch ("Tables for the Laplace Transformation and Instructions for their Use"), Springer-Verlag, Berlin and Göttingen 1947

Measuring Apparatus

Figure 2 is a schematic representation of the optical configuration of the measuring apparatus used. A ribbon lamp each is imaged on a 0.5 mm slot. An electromagnetically powered tongue of thin aluminum foil oscillates immediately in front of the slot in a direction vertical to the optical axis. With an oscillation amplitude of approximately 3 mm, it approximates a rectangular light modulation quite well. The chopped divergent light beams are collected in a semipermeable glass plate. The lens behind it ensures a parallel light beam. A slot, the height and width of which can be adjusted, and which is imaged on the detector, defines the detector area. An interference filter (slanted so as to avoid reflexes) is also located in the parallel path of the rays. Fig. 3 shows an electronic block diagram. An impedance transformer with very high input impedance is located in back of the output of the radiation detector under investigation. The impedance transformer consists of a completely regenerative operational amplifier with field-effect input stage. Its most important task is compensation of the feedback to the detector from the voltage drop at load resistor R_A. For the photoelectron multiplier, this is done by keeping the potential difference between the last dynode and the anode constant (switch position 1). In switch position 2, the positive side of the high-voltage unit is grounded in the conventional manner so that it becomes possible to measure the nonlinearity which is caused by the uncompensated voltage drop at R_A and which is used here as an example. For the guard ring photodiode (SGD-100), which is also being investigated here, the impedance transformer keeps the potential difference between electrodes G and A constantly at zero. This also makes the photoelectric current signal independent of the load resistor so that load resistors up to 10 MΩ can be used without any difficulties, something that would be senseless without an impedance transformer as the diode (for U_B = 24 V) between electrodes A and G has an intrinsic impedance of approximately 1 MΩ. A high-quality RC filter, also equipped with an operational amplifier, is located behind the impedance transformer. The RC filter strongly suppresses the basic frequencies ω_1 = 213.5

Hz, and ω_2 = 200 Hz as well as their harmonic waves. The choppers are powered by two RC generators, with the power being supplied to them via power amplifiers. Furthermore, the differential frequency $\omega_1 - \omega_2$ = 13.5 Hz of the two generator frequencies ω_1 and ω_2 is generated in a mixing stage. Two successive RC filters separate it from all undesired signals with different frequencies, and a phase advancer directs it as the reference signal to the phase-selective rectifier. Figure 4 illustrates the mechanical design of the chopper. A horizontally mobile clamping device K, with a 1.5 mm spring steel wire inside, sits on a heavy 20 mm thick brass base plate. A small ceramic permanent magnet PM and chopper SB are located at the free end of the spring steel wire. The free length of the spring steel wire was adjusted for mechanical resonance, in this state, the resultant free length was approximately 50 mm. Fixed slot S and chopper SB were blackened. The pulling electromagnet Z, supplied with approximately 2 W power by a power amplifier, generates an inhomogenous magnetic field at the location of the permanent magnet PM which transmits the propulsion energy to the chopper system. The entire chopper rests on three felt bases so that vibrations cannot be transmitted to the optical components, thus eliminating a factor which could also have resulted in frequency modulation and thus in the apparent existence of a nonlinearity.

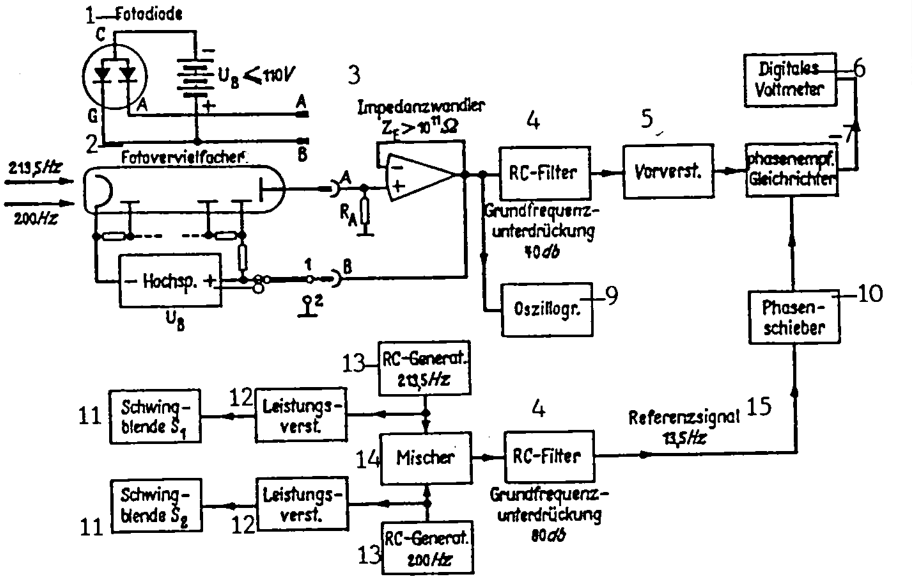

Figure 3
Electronic block diagram

1 = photodiode	9 = oscillograph
2 = photoelectron multiplier	10 = phase advancer
3 = impedance transformer	11 = chopper (S_1, S_2)
4 = RC filter, base frequency suppression 40 db/80 db	
5 = pre amplifier	12 = power amplifier
6 = digital voltmeter	13 = RC generator (213.5/200 Hz)
7 = phase-selective rectifier	14 = mixer
8 = high voltage unit	15 = reference signal

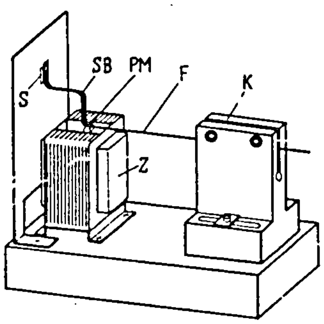

Figure 4:
Chopper Unit

Measuring Results

Figure 5 shows the results of some nonlinearity measurements from a photoelectron multiplier, model 9558. These measurements were taken without compensation for the voltage drop i × R_A at load resistor R_A (cf. Fig. 3, switch position 2). The vacuum voltage between the anode and the terminal dynode was only 41 V here. The results obtained by the dynamic method correspond to those of the constant light method within the limits of the latter's variation. The variation of the dynamically measured values is lower because the dynamic method not as demanding in terms of requiring that the light source remain constant over a period of time, as its measuring time is shorter. With the dynamic method, a measuring cycle for the frequencies selected here takes only approx. 4.8 msec. On the other hand, the measuring cycle of the constant light method takes at least 10 sec.

A third straight line shown in Fig. 5 illustrates a nonlinearity which is proportional to the photoelectric current, this was measured with the constant light method with compensated voltage drop at R_A (cf. Fig. 3, switch position 1). This is the known result of shifts in the potential in the bleeder chain. The increase of these shifts in the potential is linear to the photoelectric current load on the bleeder. All measurements on photoelectron multiplier 9558 were taken without the interference filter shown in Fig. 2 and with white light. Orientation measurements did not indicate that the length of the light waves affects nonlinearity. In conclusion, it should be emphasized that to date, the photoelectron multiplier which we used has not shown any "intrinsic" nonlinearities in any of the measurements; the nonlinearities which we observed are exclusively caused by the outer network (bleeder or shifts of the operating point for non-compensated voltage drop i × R_A). There are photoelectron multipliers which exhibit nonlinearities; these are dependent of the position and the size of the imaged cathode field.

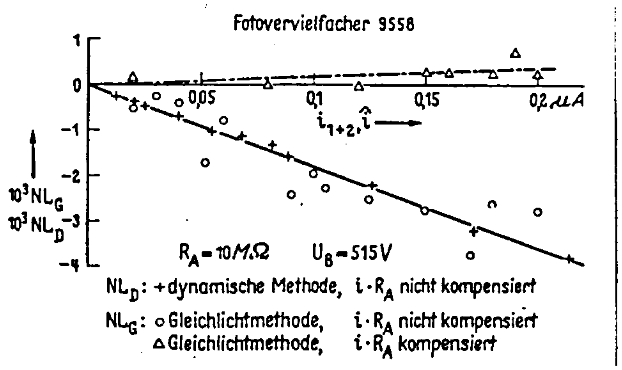

Figure 5
Nonlinearities of photoelectron multiplier 9558 as a function of the photoelectric current

dynamische Methode = dynamic method
Gleichlichtmethode = constant light method
(nicht) kompensiert = (not) compensated

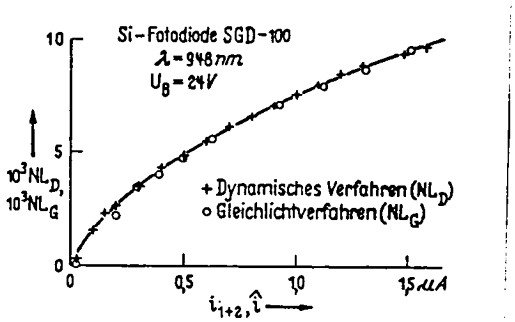

Figure 6
Nonlinearities of Photodiode SGD-100 as a function of the photoelectric current

Fig. 6 shows the results which were obtained with a silicon photodiode SGD-100 with bias voltage U_B = 24 V, and wave length λ = 948 mm. Here, too, we find good correspondence between the values obtained by the dynamic method and those measured with the constant light method. According to equation (1), it may be concluded from the exact agreement of NL_G and NL_D that the time constant of the nonlinearity satisfies the condition

$$\omega \tau \ll 1,$$

i.e.

$$\tau \ll 0{,}72 \text{ msec}$$

The measurements were performed in the circuitry according to Fig. 3, i.e. with compensation of the voltage drop at the load resistor. The dimensions of the illuminated detector area were 1 x 3 mm.

Bibliography

[1] Bischoff, K.: Z. Instrum. **69**, 143 (1961)

[2] Kunz, H.: Dissertation, Technical University Hannover, 1967

[3] Cohen, B.J., Hübner, H.-J., Sutter, E.: "Linearity Studies with Photoelectron Multipliers", Meßtechn. **11**, 288 (1968)

[4] Sanders, C.L.: Appl. Opt. **1**, 207 (1962)

[5] Stiles, W.S.: Phil. Mag. **7**, 812 (1929)

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